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URANIUM DISCARD LIMITS FOR THE K-25 PLANT

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CARBIDE AND CARBON CHEMICALS COMPANY
K-25 Plant
Oak Ridge, Tennessee

Carbide and Carbon Chemicals Corporation Operating Contractor for the U.S. Atomic Energy Commission.

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Title: URANIUM DISCARD LIMITS FOR THE K-25 PLANT

Author: I. M. Miller

A B S T R A C T

The purpose of this report is to establish specifications for discarding uranium in an impure state for use with the recovery facilities in the K-1420 building. These specifications, or discard limits, were determined on the basis of expected recovery and fluorination costs in the K-1420 building.

Discard limits were derived by assuming original uranium concentrations, calculating a total recovery cost for each concentration, and then finding that isotopic concentration or assay of uranium whose value equals the recovery cost. The uranium concentration and assay coordinates so obtained describe discard limit curves. These curves establish uranium ~~discard~~ concentrations and uranium-235 assays below which solids and liquids should be discarded.

Discard limit curves have been derived for impure solutions and solids and are shown in figures 11 and 12* of this report. Recovered oxide having assays between 0.00417 and 0.00903 weight fraction uranium-235 should be fluorinated in the feed plant because of the net saving in fluorination cost which can be realized above mixing losses in the feed plant.

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* tables 5 and 8

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URANIUM DISCARD LIMITS FOR THE K-25 PLANT

INTRODUCTION

The basis for establishing uranium discard limits at the K-25 plant is this: If the cost to recover a given quantity of uranium from an impure state to uranium hexafluoride exceeds its value as uranium hexafluoride, the uranium is discarded; if the cost to recover a given quantity of uranium in the same manner does not exceed its value as uranium hexafluoride, the material containing that uranium is saved for uranium recovery. Thus, uranium discard limits are directly dependent upon unit recovery costs and unit values of uranium. This means that if the unit value of uranium were established, uranium discard limits can be determined by evaluating unit recovery costs.

Although the cost of producing uranium at various uranium-235 concentrations has always been well known at the K-25 plant; from the plant start-up date until October, 1952, no uranium values had been established which would include the strategic and monetary worth of this element and would therefore be useful in determining uranium discard limits. Consequently, arbitrary specifications for discarding impure uranium materials were used at the K-25 plant during that time period. After unit values of uranium were established (3), a cost study was made of the then existing batch-type recovery process, and this study led to more realistic discard limit specifications at this plant (4). In addition, the establishment of uranium values resulted in the development of discard limit specifications for the Paducah plant (1). The inefficiency of the batch process and the need for enlarged decontamination facilities at the K-25 plant led to the approval of a new decontamination and recovery building (the K-1420 building) having a new continuous recovery process. Since this new recovery process is more efficient than the batch type process, unit recovery costs will be lower; hence, existing discard limit specifications are no longer applicable. Therefore, the purpose of this report is to establish new limits for discarding impure uranium materials (i.e., solutions and solids) at the K-25 plant.

New uranium discard limits have been determined and are presented in this report in graphic form; this form will quickly indicate whether any given material is to be saved or discarded. Furthermore, it will indicate whether the final processing step, fluorination, is to be done in the new recovery process or in the feed plant.

An inexpensive modification to the new recovery system which would significantly lower the new discard limits is proposed in this report. Since this modification would interfere with the converter decontamination process in the K-1420 building for at least 18 months of operation, it is not recommended that the modification be made until after this time period. Material which would be saved as a result of this modification could be stored until such time when the modification would be feasible. The lower discard limits which would result from this modification have also been determined and are presented in this report for appropriate application.

RECOMMENDATIONS AND CONCLUSIONS

It is recommended that figures 11 and 12 be the discard limit specifications for impure uranium solutions and solids, respectively, at the K-25 plant. If the uranium concentration and assay of a solution or solid are the coordinates of a point which lies below the lower curve in figure 11 or figure 12, respectively, that material should be discarded. If this point lies on or above the lower curve, the material should be stored for future uranium recovery. The signfficance of the upper curve in each figure is that if the point lies on or above the upper curve, the material can be processed in the new recovery system at any time; if the point lies below the upper curve but on or above the lower curve, the material should be stored until a 100-gallon per hour evaporator, which is to be used exclusively in the converter decontamination process for at least 18 months of operation, can be paralleled with the two pre-extraction evaporators in the new recovery process. Once this modification to the new recovery process is made, the upper curve in figures 11 and 12 should be disregarded and material meeting the specifications of the lower curve could then be processed at any time.

If any material meets the specifications called for by these curves and has an assay within the range 0.00417 to 0.00903, the final processing step for this material, fluorination, should be performed in the feed plant rather than in the K-1420 building. This assay range is indicated in figures 11 and 12.

Material for which discard is indicated may be saved for two reasons: first, the value of the material which contains uranium may be high enough to warrant the independent recovery of this material, and, second, uranium discard limits may be sufficiently lower at another Atomic Energy Commission installation to enable the economic recovery of uranium at ~~this~~ that installation.

DESCRIPTION OF THE NEW RECOVERY PROCESS

Figure 1 shows a schematic flow diagram of the new recovery process. Impure solids containing uranium are fed into the dissolver (a) where they are leached or dissolved with nitric acid. Any undissolved solids in the resulting mixture are filtered and the filtrate is pumped to always-safe* storage tanks (c). Impure uranium solutions from other sources are also fed to these storage tanks. If the uranium concentration of the solution in the storage tanks is less than 25 ~~grams per liter~~ g./l. (or 25,000 ppm), the solution is fed to the pre-extraction evaporators (d) where it is concentrated to a maximum concentration of 25 g./l. ~~evaporated to that concentration~~. The concentrated solution from the evaporator or from the storage tanks is fed to the pulse columns (e) which extract the uranium from the impure solution with solvent (tributyl phosphate). The solvent containing the purified uranium is sent to a scrubbing column (f) which removes the uranium from the solvent with water. The resulting uranium water solution** is fed to an evaporator (g) which concentrates the solution

*The storage tanks are of a design which will make them always safe from a critical radiation hazard.

**The uranium is in the form of uranyl nitrate: $UO_2(NO_3)_2$.

to 300 grams per liter. This concentrated solution is fed to a drier (h) which dries the uranium as uranyl nitrate hexahydrate, $UO_2(NO_3)_2 \cdot 6H_2O$. The uranyl nitrate hexahydrate is fed to a calciner (i) which transforms this uranium compound to uranium oxide (U_3O_8). The uranium oxide is then ground to a powder in a tube mill (j) and is then charged to a reactor (k), where it is fluorinated to uranium hexafluoride (UF_6). The gaseous uranium hexafluoride is cold trapped into cylinders (l) which are then available for feeding the uranium hexafluoride into the cascade.

METHOD

The Relationship of the Variables Which Determine Discard Limits

The Atomic Energy Commission has established the unit value of uranium at various uranium-235 concentrations or assays for uranium discard purposes (3). For ease in reference, the table of uranium values (3) is reproduced in table 1, and a curve drawn from these values is shown in figure 2. Note that the unit value of uranium varies directly with its assay. Uranium discard limits are obtained by finding that assay of uranium whose unit value equals the unit recovery cost of uranium for a given uranium concentration in the unprocessed material. It is obvious that the lower the uranium concentration, the higher the recovery cost, and thus the higher the assay of uranium whose value equals this higher recovery cost. Consequently, economic discard limits are resolved in an inverse relationship between the uranium-235 assay and the uranium concentration in the unprocessed material.

Assumptions

Since no cost experience for the new recovery process is yet available upon which to base new discard limit specifications, it was necessary to use proposed batch sizes, equipment throughputs, and man-hours to calculate the recovery cost for each assumed uranium concentration in the unprocessed material. In addition, a maximum processing rate of 15 kilograms of uranium per eight-hour day is assumed. Calculations were based on the most efficient operation and utilization of the equipment and on the most efficient utilization of man power to arrive at the lowest possible recovery costs and thus the lowest possible discard limits. This assures the processing of any marginal material, the saving of which might otherwise be in doubt. Other assumptions used to calculate recovery costs are listed in appendix A.

Calculation of Discard Limits

The recovery cost for each assumed uranium concentration in the starting material was calculated by summing the direct costs* in the recovery process and then adding 107 per cent of the direct labor for plant expense, 60 per cent of direct labor for maintenance materials and labor, and 5 per cent of direct labor for building utilities. These percentages of direct labor are based on the most recent cost experience for the K-25 plant. Table 2 shows unit costs for the processing of impure uranium solutions to uranium hexafluoride. For each type of

*Budgeted costs for fiscal year 1955.

direct cost listed in table 2 a sample calculation is given in appendix B. Table 3 shows unit costs for the processing of impure uranium solids to impure uranium solutions. For each type of direct cost listed in table 3 a sample equation is given in appendix C. The initial uranium concentrations of the solid which are listed in table 3 were calculated from the uranium concentrations of the solutions which are listed in table 2. This calculation is also shown in appendix C. Table 4 shows the total unit recovery cost for each initial uranium concentration in the solution and solid. The total recovery costs for solids in table 4 were obtained by adding each total recovery cost in table 3 to the corresponding total recovery cost in table 2. The uranium-235 assay shown beside each total unit recovery cost in this table is the assay of uranium whose unit value equals the total unit recovery cost. The assay was found by locating on figure 2 the value of uranium equal to the total unit recovery cost and reading from the curve the required uranium-235 assay. The uranium concentration and uranium-235 assay values in table 4 form coordinates which determine two discard limit curves, one for impure uranium solutions and one for impure uranium solids. These two curves are shown in figures 3 and 4, respectively. Before these curves can be accepted as discard limit specifications for the K-25 plant, they must be altered for the reasons and in the manner described below.

Effect of the Feed Plant Fluorination Cost on Discard Limits

It should be emphasized that the discard limit curves shown in figures 3 and 4 are based upon the cost of fluorinating the recovered uranium oxide to uranium hexafluoride in the K-1420 building. Since uranium oxides can be fluorinated in like manner at a much lower cost in the feed plant, discard limits will be lower for uranium having an assay at or near the assay of uranium processed in the feed plant. Since an increasing mixing loss is sustained with an increasing difference in assay between the uranium oxide to be fluorinated and the uranium oxide in the feed plant, there must be upper and lower assay limits wherein the mixing loss sustained in the feed plant does not exceed the saving to be realized in processing the recovered uranium oxide in the feed plant. For this purpose a mixing loss equation is necessary to evaluate the lower and upper limits of those assays for which material can be economically processed. In turn, a uranium cost equation is necessary to determine the constant in the mixing loss equation. A uranium cost equation was developed by fitting an equation of the form

$$Y = A + BX + CX^2 \qquad (1)$$

to new uranium cost data (2) by the method of least squares over the assay range 0.0040 to 0.0100. This equation is

$$Y = -11.147 + 2500X + 637{,}143X^2 \qquad (2)$$

where Y = standard cost of uranium with depreciation for fiscal year 1955, dollars per kilogram ~~or~~ of uranium as uranium hexafluoride.

X = uranium-235 assay, weight fraction uranium-235.

A mixing loss equation was derived in the manner outlined in appendix D. This equation is

$$L = \frac{637{,}143M\,(X_1 - X_2)^2}{1 + M/N} \tag{3}$$

where L = mixing loss, dollars

M = uranium having an assay X_1, kilograms

N = uranium having an assay X_2, kilograms

X_1, X_2 = assays of M and N, respectively, weight fraction uranium-235.

Note that the coefficient of X_2 in equation (2) was used as the constant in the above equation. The maximum mixing loss, L_{max}, would be encountered when a finite quantity M is added to an infinite quantity N, which is approximately the case in the feed plant. Therefore, the ratio of M/N approaches zero and equation (3) reduces to

$$L_{max} = 637{,}143\,M\,(X_1 - X_2)^2 \tag{4}$$

A saving of $3.76 per kilogram of uranium is realized by processing uranium oxide through the feed plant. By setting this saving equal to the mixing loss in equation (4), by letting M be unity, and by setting $X_1 = 0.0066$ (the average assay of material processed in the feed plant), the upper and lower assay limits, X_2, were solved for and were found to be 0.00903 and 0.00417. This means that small amounts of uranium oxide having assays between these limits can be economically processed in the feed plant along with the main stream of Hanford tails material. It is to be noted, however, that should the stream of recovered oxide become larger, e.g., ton quantities, the permissible assay band widens. The processing of large quantities of uranium oxide is not to be precluded provided that the amount of material is large enough to require the full fluorination facilities of the feed plant, the assay is below critical hazard specifications, and provided the fluorination cost in the feed plant does not exceed the value of the material.

Discard limits were re-evaluated within the assay band indicated above by using equation (4) and the processing saving of $3.76 per kilogram of uranium. The method of calculating values which determine the revised discard limit curve within this assay band is given in appendix E. Table 5 shows the values which determine the revised discard limit curves. These curves are shown in figures 5 and 6. The curves in figures 5 and 6 are the same as those in figures 3 and 4 except for the indicated revision to each.

Effect of Minor Modification to Recovery System on Discard Limits

The cost analysis (table 2) which led to the discard limits shown in figures 5 and 6 indicated that the limiting factor in the recovery process was the two pre-extraction evaporators which would be used at their full capacity of 35 gallons per hour per evaporator. Additional evaporator capacity to relieve this bottleneck could be provided for by paralleling with these two evaporators an evaporator of 100-gallon per hour capacity which is to be used in the converter decontamination process. This evaporator will not be available for paralleling with the other two evaporators for at least 18 months of operation; however, if the results of a cost analysis can show that discard limits would be significantly lowered with this modification, material which would be saved as a result of this modification could be stored until such time when the modification would be feasible. Consequently, a cost analysis based on this modification was made to determine new discard limits which could be compared with those in figure 4. The procedure used for making this cost analysis and for deriving the discard limit curves based on this analysis is the same as that previously described under the paragraph heading "Calculation of Discard Limits." Table 6 shows unit costs for the processing of impure uranium solutions to uranium hexafluoride. Table 7 shows the total unit recovery cost and the assay of uranium whose value is equal to this cost for each initial uranium concentration in the solution and solid. The total recovery costs for solid material in table 7 were obtained by adding each total recovery cost in table 6 to the corresponding total recovery cost in table 3. The uranium concentration and uranium-235 assay values in table 7 form coordinates which determine two discard limit curves, one for impure uranium solutions and one for impure uranium solids. These two curves are shown in figures 7 and 8. The curves in figures 7 and 8 were revised by the same procedure previously discussed under the above section heading "Effect of the Feed Plant Fluorination Costs on Discard Limits" to yield the uranium discard limit curves shown in figures 9 and 10. Data supporting these curves are shown in table 8. The curves in figures 9 and 10 should be used as the uranium discard limit specifications for the K-25 plant when the recovery system is altered in the manner described above.

For comparison purposes, the discard limit curves for solutions which apply to the unmodified and modified new recovery system have been redrawn from figures 5 and 9 in figure 11. Likewise, the discard limit curves for solids have been redrawn from figures 6 and 10 in figure 12. Note that the curves for the modified system are appreciably lower than those for the unmodified system in both figures 11 and 12. Thus, material which would otherwise be discarded would be saved and stored until the recovery system is altered in the manner discussed above.

Use of the Curves

Figures 5 and 6 represent the discard limit specifications for impure uranium solutions and solids, respectively, which apply to the recovery system in its present, unmodified form. Similarly, figures 9 and 10 represent the discard limit specifications for impure solutions and solids, respectively, which will apply to the recovery system when a 100-gallon per hour evaporator in the K-1420 building is tied into the recovery system. This evaporator will not be available for this purpose for at least 18 months. To illustrate the use of these curves, refer to the curve in figure 5 which is applicable to solutions and consider a solution of known uranium concentration and assay. The uranium concentration and assay are coordinates of a point that may lie above, on, or below the discard limit curve for solutions. If the point falls on or above the curve, the solution is saved for processing; if the point falls below the curve, the solution is discarded. The curve in figure 5 establishes minimum limits for discarding solutions; i.e., ~~that is,~~ all solutions having uranium concentrations below 1 ppm of uranium or assays below 0.00354 should be discarded. Likewise, according to the curve in figure 6, all solids having uranium concentrations below 16 x 10^{-6} ~~grams~~ g. U/g. ~~of uranium/gram~~ or assays below 0.00380 should be discarded.

Note that there are two curves in each of figures 11 and 12. The upper curve in figure 11 is the same as the curve in figure 5; likewise, the upper curve in figure 12 is the curve in figure 6. The lower of the two curves in figure 11 is the same as the curve in figure 9; similarly, the lower curve in figure 12 is the same as the curve in figure 10. If the uranium concentration and assay of a material under consideration are the coordinates of a point which lies on the lower curve or in the area between the two curves, that material can be stored until such time as the modification described above is feasible.

If any material meets the specifications called for by these curves and has an assay within the range 0.00417 to 0.00903, the final processing step for this material, fluorination, should be performed in the feed plant rather than in the K-1420 building.

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TABLE 1

VALUE OF URANIUM AS URANIUM HEXAFLUORIDE
AT VARIOUS ISOTOPIC CONCENTRATIONS*

Concentration, weight fraction uranium-235	Value of Contained Uranium as Uranium Hexafluoride, $/kg.	Concentration, weight fraction uranium-235	Value of Contained Uranium as Uranium Hexafluoride, $/kg.
0.00200	0	0.04000	1,440.00
.00250	1.375	.05000	1,881.00
.00300	6.90	.06000	2,331.00
.00350	15.23	.07000	2,786.00
.00400	25.32	.08000	3,244.00
.00450	36.81	.09000	3,703.50
.00500	49.60	.10000	4,170.00
.00550	63.25	.15000	6,525.00
.00600	77.82	.20000	8,940.00
.00650	92.82	.25000	~~18,387.50~~ 11,387.50
.00700	108.43	.30000	~~13~~,848.00
.00750	124.50	.40000	18,840.00
.00800	141.12	.50000	23,950.00
..00850	158.27	.60000	29,160.00
.00900	175.59	.70000	34,510.00
.00950	193.23	.80000	40,240.00
.01000	211.00	.82000	41,492.00
.01200	283.20	.84000	42,756.00
.01400	358.96	.86000	44,118.00
.01600	437.60	.88000	45,672.00
.01800	517.32	.90000	47,340.00
.02000	598.40	.91000	48,230.00
.02500	804.00	.92000	49,220.00
0.03000	1,013.40	0.93000	50,406.00

*Reproduced from reference (3).

TABLE 2

URANIUM RECOVERY COSTS - IMPURE SOLUTION TO URANIUM HEXAFLUORIDE

Initial Concentration		Preparation for Evaporation					First Evaporation		
ppm U	g. U/gal.	Initial Batch Size, gal.	Contained Uranium, kg.	Nitric Acid Cost, $/kg. U	Labor Cost, $/kg. U	Sampling, Analytical Cost, $/kg. U	Concentration Effect	Water Evaporated, gal.	Steam Cost, $/kg. U
1.05	0.00397	653	0.002592	3,835.81	7,366.34	3,371.04	7-1	560	1,282.67
1.09	0.00413	653	0.002697	3,695.04	7,096.11	3,247.34	7-1	560	1,235.59
4	0.01514	653	0.009886	1,006.90	1,933.66	884.90	7-1	560	336.70
10	0.03785	653	0.02472	402.76	773.47	353.96	7-1	560	134.68
50	0.18925	653	0.12358	80.55	154.69	70.79	7-1	560	26.94
100	0.37850	653	0.24716	40.28	77.34	35.40	7-1	560	13.47
250	0.94625	653	0.6179	16.11	30.94	14.16	7-1	560	5.39
500	1.8925	653	1.2358	8.06	15.47	7.08	7-1	560	2.69
1,000	3.785	653	2.4716	4.03	7.73	3.54	7-1	560	1.35
2,000	7.570	653	4.9432	2.02	3.87	1.77	7-1	560	0.68
5,000	18.925	700	13.2475	1.13	1.55	0.71	5-1	560	0.27
10,000	37.850	396.3	15.0	1.13	0.77	0.36	2.5-1	237.8	0.09
15,000	56.775	264.2	15.0	1.13	0.51	0.24	1.67-1	105.7	0.06
25,000	94.625	158.5	15.0	1.13	0.31	0.14	1-1	0.0	0.00

TABLE 2

URANIUM RECOVERY COSTS - IMPURE SOLUTION TO URANIUM HEXAFLUORIDE (Cont.)

Initial Concentration, ppm U	First Evaporation (cont.)		Extraction	Second Evaporation			Drying	Calcining	Grinding
	Labor Cost, \$/kg. U	Solution Vol. after Evap., gal.	Labor Cost, \$/kg. U	Water Evaporated, gal.	Steam Cost, \$/kg. U	Labor Cost, \$/kg. U	Labor Cost, \$/kg. U	Labor Cost, \$/kg. U	Labor Cost, \$/kg. U
1.05	1,841.56	93	2,854.42	92.998	212.76	178.38	0.16	0.16	0.16
1.09	1,773.98	93	2,749.67	92.998	204.95	171.83	0.16	0.16	0.16
4	483.42	93	749.29	92.99	55.85	46.83	0.16	0.16	0.16
10	193.36	93	299.71	92.98	22.34	18.73	0.16	0.16	0.16
50	38.67	93	59.94	92.88	4.47	3.74	0.16	0.16	0.16
100	19.34	93	29.97	92.78	2.23	1.87	0.16	0.16	0.16
250	7.73	93	11.99	92.46	0.89	0.76	0.16	0.16	0.16
500	3.87	93	5.99	91.91	0.44	0.37	0.16	0.16	0.16
1,000	1.93	93	3.00	90.83	0.22	0.18	0.16	0.16	0.16
2,000	0.96	93	1.50	88.66	0.11	0.09	0.16	0.16	0.16
5,000	0.39	140	0.84	128.34	0.06	0.05	0.16	0.16	0.16
10,000	0.19	158.5	0.84	145.29	0.06	0.05	0.16	0.16	0.16
15,000	0.12	158.5	0.84	145.29	0.06	0.05	0.16	0.16	0.16
25,000	0.00	158.5	0.84	145.29	0.06	0.05	0.16	0.16	0.16

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TABLE 2

URANIUM RECOVERY COSTS - IMPURE SOLUTION TO URANIUM HEXAFLUORIDE (Cont.)

Initial Concentration, ppm U	Grinding (cont.), Sampling, Analytical Cost, $/kg.U	Conversion: Fluorine Cost, $/kg. U	Conversion: Labor Cost, $/kg. U	Conversion: Sampling, Analytical Cost, $/kg. U	Control Sampling Labor Cost, $/kg. U	Total Direct Cost, $/kg. U	Total Direct Labor Cost, $/kg. U	Overhead, Maintenance, and Utilities Cost, $/kg. U	Total Recovery Cost, $/kg. U
1.05	1.30	2.64	1.27	1.38	3,205.39	24,155.44	15,447.84	26,570.28	50,725.72
1.09	1.30	2.64	1.27	1.38	3,087.76	23,269.34	14,881.10	25,595.49	48,864.83
4	1.30	2.64	1.27	1.38	841.42	6,346.04	4,056.37	6,976.96	13,323.00
10	1.30	2.64	1.27	1.38	336.57	2,542.65	1,623.59	2,792.57	5,335.22
50	1.30	2.64	1.27	1.38	67.31	514.17	326.10	560.89	1,075.06
100	1.30	2.64	1.27	1.38	33.66	260.63	163.93	281.96	542.59
250	1.30	2.64	1.27	1.38	13.46	108.50	66.63	114.60	223.10
500	1.30	2.64	1.27	1.38	6.74	57.78	34.19	58.81	116.59
1,000	1.30	2.64	1.27	1.38	3.37	32.42	17.96	30.89	63.31
2,000	1.30	2.64	1.27	1.38	1.68	19.75	9.85	16.94	36.69
5,000	1.30	2.64	1.27	1.38	0.62	12.69	5.20	8.94	21.63
10,000	1.30	2.64	1.27	1.38	0.55	11.11	4.15	7.14	18.25
15,000	1.30	2.64	1.27	1.38	0.55	10.63	3.82	6.57	17.20
25,000	1.30	2.64	1.27	1.38	0.55	10.15	3.50	6.02	16.17

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TABLE 3

PROCESSING COSTS - IMPURE SOLIDS TO SOLUTIONS

Uranium Concentration in Final Solution, ppm	Uranium Concentration in Initial Solid, g. U/g.	Nitric Acid Cost, $/kg. U	Labor Cost, $/kg. U	Total Direct Cost, $/kg. U	Overhead, Maintenance, and Utilities Cost, $/kg. U	Total Processing Cost, $/Kg. U
3	0.000014	31,320.92	3,825.80	35,146.72	6,580.38	41,727.10
4	.000018	23,491.28	2,869.42	26,360.70	4,935.40	31,296.10
10	.000046	9,376.09	1,145.27	10,521.36	1,969.86	12,491.22
50	.000230	1,875.22	229.05	2,104.27	393.97	2,498.24
100	.000459	939.65	114.78	1,054.43	197.42	1,251.85
250	.001148	375.04	45.81	420.85	78.79	499.64
500	.00230	187.52	23.93	211.45	41.16	252.61
1,000	.00459	93.97	11.48	105.45	19.75	125.20
2,000	.00918	46.98	5.73	52.71	9.86	62.57
5,000	.0230	18.75	2.29	21.04	3.94	24.98
10,000	.0459	9.40	1.15	10.55	1.98	12.53
15,000	.0688	6.26	.77	7.03	1.32	8.35
25,000	0.1148	3.76	.46	4.22	.79	5.01

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TABLE 4

URANIUM RECOVERY COSTS AND DISCARD LIMIT ASSAYS FOR SOLIDS AND SOLUTIONS

Solids			Solutions		
Uranium Concentration, g. U/g.	Total Uranium Recovery Cost, $/kg. U	Discard Limit Assay, weight fraction U-235	Uranium Concentration, ppm	Total Uranium Recovery Cost, $/kg. U	Discard Limit Assay, weight fraction U-235
0.000018	44,619.10	0.867	1.05	50,725.72	0.934
.000046	17,826.44	.380	1.09	48,864.43	.917
.000230	3,573.30	.0871	4	13,323.00	.289
.000459	1,794.44	.0481	10	5,335.22	.1249
.001148	722.74	.0231	50	1,075.06	.0315
.00230	369.20	.01426	100	542.59	.01866
.00459	188.51	.00938	250	223.10	.01034
.00918	99.26	.00670	500	116.59	.00723
.0230	46.61	.00488	1,000	63.31	.00549
.0459	30.78	.00424	2,000	36.69	.00449
.0688	25.55	.00401	5,000	21.63	.00383
0.1148	21.18	0.00380	10,000	18.25	.00365
			15,000	17.20	.00360
			25,000	16.17	0.00354

TABLE 5

REVISED URANIUM RECOVERY COSTS AND DISCARD LIMIT ASSAYS FOR SOLIDS AND SOLUTIONS

Solids			Solutions		
Uranium Concentration, g. U/g.	Total Uranium Recovery Cost, $/kg. U	Discard Limit Assay, weight fraction U-235	Uranium Concentration, ppm	Total Uranium Recovery Cost, $/kg. U	Discard Limit Assay, weight fraction U-235
0.000018	44,619.10	0.867	1.05	50,725.72	0.934
.000046	17,826.44	.380	1.09	48,864.43	.917
.000230	3,573.30	.0871	4	13,323.00	.289
.000459	1,794.44	.0481	10	5,335.22	.1249
.001148	722.74	.0231	50	1,075.06	.0315
.00230	369.20	.01426	100	542.59	.01866
.00459	188.51	.00938	250	223.10	.01034
.00500	176.50	.00903	319	176.50	.00903
.00918	95.51	.00658	500	113.08	.00713
.0230	44.73	.00480	1,000	60.34	.00540
.0459	30.57	.00423	2,000	35.77	.00445
.0530	29.00	.00417	2,850	29.00	.00417
.0688	25.55	.00401	5,000	21.63	.00383
0.1148	21.18	0.00380	10,000	18.25	.00365
			15,000	17.20	.00360
			25,000	16.17	0.00354

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TABLE 6

URANIUM RECOVERY COSTS ON REVISED SYSTEM - IMPURE SOLUTION TO URANIUM HEXAFLUORIDE

Initial Concentration		Preparaton for Evaporation					First Evaporation		
ppm U	g. U/gal.	Initial Batch Size, gal.	Contained Uranium, kg.	Nitric Acid Cost, $/kg. U	Labor Cost, $/kg. U	Sampling, Analytical Cost, $/kg. U	Concentration Effects*	Water Evaporated, gal.	Steam Cost, $/kg. U
1	0.00378	1,542	0.005836	3,331.20	3,275.94	1,499.20	10-1, 7-1	1,360	1,385.30
3	0.01136	1,542	0.017509	1,110.37	1,091.95	499.72	10-1, 7-1	1,360	461.75
4	0.01514	1,542	0.023346	832.80	818.98	374.80	10-1, 7-1	1,360	346.32
10	0.03785	1,542	0.058365	333.12	327.59	149.92	10-1, 7-1	1,360	138.53
50	0.18925	1,542	0.29182	66.62	65.51	29.98	10-1, 7-1	1,360	27.71
100	0.3785	1,542	0.58365	33.31	32.76	14.99	10-1, 7-1	1,360	13.85
250	0.9462	1,542	1.4591	13.32	13.11	6.00	10-1, 7-1	1,360	5.54
500	1.8925	1,542	2.9182	6.66	6.55	3.00	10-1, 7-1	1,360	2.77
1,000	3.785	1,542	5.8365	3.33	3.27	1.50	10-1, 7-1	1,360	1.38
2,000	7.570	1,542	11.6729	1.66	1.64	0.75	10-1, 7-1	1,360	0.69
5,000	18.925	792.6	15.0	1.13	0.66	0.30	5-1, 5-1	634.1	0.28
10,000	37.85	396.3	15.0	1.13	0.33	0.15	- , 2.5-1	237.8	0.09
15,000	56.775	264.2	15.0	1.13	0.23	0.10	- , 1.67-1	105.7	0.06
25,000	94.625	158.5	15.0	1.13	0.13	0.06	- , 1-1	0.0	0.00

* ______ in the 100-gallon per hour evaporator and in the 2-35 gallon per hour evaporators, respectively. Net concentration effect is 9.153-1.

TABLE 6

URANIUM RECOVERY COSTS ON REVISED SYSTEM - IMPURE SOLUTION TO URANIUM HEXAFLUORIDE (Cont.)

Initial Concentration, ppm U	First Evaporation (cont.) Labor Cost, $/kg. U	First Evaporation (cont.) Solution Vol. after Evap., gal.	Extraction Labor Cost, $/kg. U	Second Evaporation Water Evaporated, gal.	Second Evaporation Steam Cost, $/kg. U	Second Evaporation Labor Cost, $/kg. U	Drying Labor Cost, $/kg. U	Calcining Labor Cost, $/kg. U	Grinding Labor Cost, $/kg. U
1	818.96	182	2,484.26	181.99	185.30	155.19	0.16	0.16	0.16
3	272.98	182	828.07	181.98	61.76	51.72	.16	.16	.16
4	204.74	182	621.07	181.98	46.32	38.79	.16	.16	.16
10	81.90	182	248.43	181.95	18.53	15.52	.16	.16	.16
50	16.38	182	49.69	181.72	3.71	3.11	.16	.16	.16
100	8.19	182	24.84	181.45	1.85	1.55	.16	.16	.16
250	3.27	182	9.94	180.61	0.74	0.62	.16	.16	.16
500	1.64	182	4.96	179.22	0.37	0.31	.16	.16	.16
1,000	0.82	182	2.48	176.45	0.18	0.15	.16	.16	.16
2,000	0.41	182	1.24	170.9	0.09	0.08	.16	.16	.16
5,000	0.32	158.5	0.84	166.8	0.06	0.05	.16	.16	.16
10,000	0.16	158.5	0.84	166.8	0.06	0.05	.16	.16	.16
15,000	0.10	158.5	0.84	166.8	0.06	0.05	.16	.16	.16
25,000	0.00	158.5	0.84	166.8	0.06	0.05	0.16	0.16	0.16

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TABLE 6

URANIUM RECOVERY COSTS ON REVISED SYSTEM - IMPURE SOLUTION TO URANIUM HEXAFLUORIDE (Cont.)

Initial Concentration, ppm U	Grinding (cont.), Sampling, Analytical Cost, $/kg.U	Conversion			Control Sampling Labor Cost, $/kg. U	Total Direct Cost, $/kg. U	Total Direct Labor Cost, $/kg. U	Overhead, Maintenance, and Utilities Cost, $/kg. U	Total Recovery Cost, $/kg. U
		Fluorine Cost, $/kg. U	Labor Cost, $/kg. U	Sampling, Analytical Cost, $/kg. U					
1	1.30	2.64	1.27	1.38	1,425.49	14,567.91	8,161.59	14,037.93	28,605.84
3	1.30	2.64	1.27	1.38	475.15	4,860.54	2,721.62	4,681.19	9,541.73
4	1.30	2.64	1.27	1.38	356.37	3,647.26	2,041.70	3,511.72	7,158.98
10	1.30	2.64	1.27	1.38	142.55	1,463.16	817.74	1,406.51	2,869.67
50	1.30	2.64	1.27	1.38	28.51	298.29	164.95	283.71	582.00
100	1.30	2.64	1.27	1.38	14.26	152.67	83.35	143.36	296.03
250	1.30	2.64	1.27	1.38	5.70	65.31	34.39	59.15	124.46
500	1.30	2.64	1.27	1.38	2.86	36.19	18.07	31.08	67.27
1,000	1.30	2.64	1.27	1.38	1.42	21.60	9.89	17.01	38.61
2,000	1.30	2.64	1.27	1.38	.72	14.35	5.84	10.04	24.39
5,000	1.30	2.64	1.27	1.38	.55	11.26	4.17	7.17	18.43
10,000	1.30	2.64	1.27	1.38	.55	10.43	3.68	6.33	16.76
15,000	1.30	2.64	1.27	1.38	.55	10.19	3.52	6.05	16.24
25,000	1.30	2.64	1.27	1.38	.55	9.89	3.32	5.71	15.60

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TABLE 7

URANIUM RECOVERY COSTS AND DISCARD LIMIT ASSAYS FOR THE MODIFIED RECOVERY SYSTEM

Solids			Solutions		
Uranium Concentration, g. U/g.	Total Uranium Recovery Cost, $/kg. U	Discard Limit Assay, weight fraction U-235	Uranium Concentration, ppm	Total Uranium Recovery Cost, $/kg. U	Discard Limit Assay, weight fraction U-235
0.000014	51,268.83	0.937	1	28,605.84	0.590
.000018	38,455.08	0.769	3	9,541.73	0.213
.000046	15,360.89	0.330	4	7,158.98	0.1650
.000230	3,080.24	0.0752	10	2,869.67	0.0723
.000459	1,547.88	0.0425	50	582.00	0.01962
.001148	624.10	0.0207	100	296.03	0.01238
.00230	319.88	0.0130	250	124.46	0.00750
.00459	163.81	0.00869	500	67.27	0.00565
.00918	86.96	0.00630	1,000	38.61	0.00457
.0230	43.41	0.00475	2,000	24.39	0.00399
.0459	29.29	0.00419	5,000	18.43	0.00367
.0688	24.59	0.00398	10,000	16.76	0.00359
0.1148	20.61	0.00380	15,000	16.24	0.00355
			25,000	15.60	0.00351

TABLE 8

REVISED URANIUM RECOVERY COSTS AND DISCARD LIMIT ASSAYS FOR THE MODIFIED RECOVERY SYSTEM

Solids			Solutions		
Uranium Concentration, g. U/g.	Total Uranium Recovery Cost, $/kg. U	Discard Limit Assay, weight fraction U-235	Uranium Concentration, ppm	Total Uranium Recovery Cost, $/kg. U	Discard Limit Assay, weight fraction U-235
0.000014	51,268.83	0.937	1	28,605.84	0.590
.000018	38,455.08	0.769	3	9,541.73	0.213
.000046	15,360.89	0.330	4	7,158.98	0.1650
.000230	3,080.24	0.0752	10	2,869.67	0.0723
.000459	1,547.88	0.0425	50	582.00	0.01962
.001148	624.10	0.0207	100	296.03	0.01238
.00230	319.88	0.0130	173	176.50	0.00903
.00429	176.50	0.00903	250	121.22	0.00739
.00918	83.26	0.00618	500	64.09	0.00552
.0230	41.83	0.00469	1,580	29.00	0.00417
.0480	29.00	0.00417	2,000	24.39	0.00399
.0688	24.59	0.00398	5,000	18.43	0.00367
0.1148	20.61	0.00380	10,000	16.76	0.00359
			15,000	16.24	0.00355
			25,000	15.60	0.00351

APPENDIX A

ASSUMPTIONS

This appendix includes all of the important assumptions which were used to calculate unit recovery costs.

Man-Hours. The following is a list of the nine individual steps in the recovery process and the number of man-hours per eight-hour day assigned to each step:

Step	Man-Hours per Eight-Hour Day
1. Leaching or dissolving	3 /batch
2. Preparation for evaporation	8
3. First evaporation	2
4. Extraction	8
5. Second evaporation	1
6. Drying	1
7. Calcining	1
8. Grinding	1
9. Conversion	8
Total	33

Material Requirements and Flows. The basic assumptions concerning material requirements and flows are described after each indicated step below as follows:

1. Leaching or dissolving. All solids are assumed to be aluminum oxide (Al_2O_3) and the amount of nitric acid required to dissolve each pound of aluminum oxide is the stoichiometric amount of 13N nitric acid required to do this.

2. Preparation for evaporation. The initial batch size to be processed is governed by the maximum capacity of the evaporators or by the maximum of ~~15~~ 45 kilograms of uranium processed per ~~eight~~ 24-hour day, whichever is the controlling factor. Every solution having a uranium concentration of less than 25,000 ppm requires processing in the first evaporation step. An amount of 13N nitric acid is added to this solution such that the nitric acid concentration in the solution after the first evaporation step is ~~3N~~ 3.5N. One sample is withdrawn from each batch for uranium and uranium-235 analysis.

3. First evaporation. The maximum uranium concentration effected in this step is 25,000 ppm. The concentration effect in this step for continuous is no greater than ~~4~~ 3 to 1. Evaporation capacity of the two evaporators is ~~560~~ 1680 gallons of ~~water evaporated~~ feed solution per ~~eight hour~~ 24 hour day. (~~Steam utilization for both this step and the second evaporation step is 80 per cent efficient; that is, 0.8 pounds of water evaporated per pound of steam condensed.~~) ?

4. Extraction. Solutions entering this step have a maximum uranium concentration of 25,000 ppm and a nitric acid concentration of ~~3N~~ 3.5N. Sufficient nitric acid must be added if necessary to assure that this nitric acid concentration is attained. No change in uranium concentration is effected in this step. (Extraction capacity of the ~~3 pulse~~ columns and 3 scrubbing columns is 240 gallons of solution per eight-hour day.) ?

5. Second evaporation. All solutions fed to the evaporators in this step are concentrated to 300 grams of uranium per liter of solution. The capacity of the 3 evaporators in this step is 480 gallons per eight-hour day.

6. Drying, calcining, and grinding. The one man-hour per eight-hour day required for each of these steps is sufficient for a maximum throughput of 15 kilograms of uranium through each of these steps per eight-hour day.

7. Conversion. Fluorine utilization for this step is 80 per cent efficient; that is, 80 per cent of the fluorine used will react with the uranium oxide in this step.

APPENDIX B

SAMPLE CALCULATIONS OF VALUES SHOWN IN TABLE 2

all of the following calculations are based on an 8-hour day.

1. Initial concentration, g. U/gal~~lon~~. of solution.

Initial concentration, g. U/gal~~lon~~. =

$$\frac{\text{initial concentration, ppm U (mg./l.) x 3.785 l./gal.}}{\text{1,000 mg./g.}}$$

2. Initial batch size, gal~~lon.~~.

Water evaporated in first evaporation step, gal~~lons~~. =

initial batch size, gal~~lons~~. - ~~solution~~ soln. vol~~ume~~. after evaporation, gallons

$$= \text{initial batch size, gal.} - \frac{\text{initial batch size, gal.}}{\text{concentration effect in the first evaporation step}}$$

From the first and last members of this equality, obtain

initial batch size, gal~~lon~~. =

$$\frac{\text{water evaporated, gal. x concentration effect}}{\text{concentration effect - 1}}$$

This equation is limited by 3 considerations, i.e.:

(1) The concentration effect is either 7 to 1 or the ratio of 25,000 ppm U to the initial concentration, ppm U, whichever is lower.

(2) The maximum capacity of the evaporators in the first evaporation step is 560 gal~~lons~~. of water evaporated~~, per eight-hour day.~~.

(3) The initial batch size contains no more than 15 ~~kilograms.~~ kg. of uranium.

If item (3) cannot be fulfilled after applying items (1) and (2), the initial batch size is calculated as follows:

$$\text{Initial batch size, gal}\cancel{\text{lon}}. = \frac{\text{15 kg. U x 1,000 g./kg.}}{\text{initial concentration, g. U/gal.}}$$

3. Uranium contained in initial batch size, kilograms.

= Uranium processed, kg. ~~(per eight-hour day)~~.

Uranium processed, kg. = initial batch size, gal. x initial concentration, g./gal. x 0.001 kg./gm.

4. Nitric acid cost, \$/kg. U

$ 0.377 0.356/gal. acid

Nitric acid cost, \$/kg. U =

$$\frac{\text{(0.3 gal. acid/gal. solution)* x initial batch size, gal. x \$/gal. acid}}{\text{concentration effect in first evaporation step x kg U}}$$

5. Labor cost, \$/kg. U (typical)

Labor cost, \$/kg. U =

$$\frac{\text{Man-hours assigned***}}{\text{uranium processed, kg.***}} \times \frac{\text{equipment usage, gal. or kg. U***}}{\text{equipment capacity, gal. or kg. U}} \times \text{\$/man-hour}$$

6. Sampling and Analytical Cost, \$/kg. U (typical)

Sampling and analytical cost, \$/kg. U =

$$\frac{\text{Sampling and analytical cost, \$***}}{\text{Quantity sampled, kg. U}}$$

7. Steam Cost, \$/kg. U (typical)

Steam cost, \$/kg. U =

$$\frac{\text{8.345 lbs./gal. water x water evaporated, gal. x \$/lb. steam used}}{\text{0.8 lbs. }\cancel{\text{steam used}}\text{ water evaporated/lb. }\cancel{\text{water evaporated}}\text{ steam used x uranium processed, kg.}}$$

*Derived on the basis of diluting 13N acid to 3N acid.

~~**On basis of eight-hour day.~~

***Laboratory data.

In this equation

Water evaporated =

soln.
~~solution~~ vol~~ume~~. before evaporation x $\frac{\text{(concentration effect - 1)}}{\text{concentration effect}}$

$2.00/lb. F_2

8. Fluorine cost, $/kg. U

Fluorine cost, \$/kg. U = $\frac{\text{19.8 lbs. fluorine* x \$/lb. fluorine}}{\text{15 kg. U}}$

9. Control sample cost, $/kg. U

Control sample cost, $/kg. U =

$\frac{\text{3.2 man-hours } \cancel{\text{per eight hour day}} \text{ x \$/man-hour}}{\text{uranium processed } \cancel{\text{per eight hour day}}\text{, kg.}}$

*Theoretical amount of fluorine required to fluorinate 15 kg. of uranium at 80% conversion.

APPENDIX C

SAMPLE CALCULATIONS OF VALUES SHOWN IN TABLE 3

all of the following calculations are based on an 8-hour day.

1. Uranium concentration in initial solid, g. U/g.

   Uranium concentration in final ~~solution~~ soln., ppm =

$$\frac{\text{lbs. U/lb. solid} \times 453.59 \text{ g. U/lb. U} \times 1{,}000 \text{ ppm/(g. U/l.)} \times 0.2462 \text{ gal./l.}}{0.55 \text{ gal. nitric acid/lb. solid*}}$$

   This equation is solved for lbs. U/lb. solid = g. U/g. solid

   to obtain

   g. U/g. solid = 4.59×10^{-6} x uranium concentration in final ~~solution~~ soln., ppm.

2. Nitric acid cost, \$/kg. U

   Nitric acid cost, \$/kg. U =

$$\frac{0.55 \text{ gal. nitric acid/lb. solid*} \times \text{\$/gal. nitric acid}}{\text{(lbs. U/lb. solid or g. U/g. solid)} \times 0.45359 \text{ kg. U/lb. U}}$$

3. Labor cost, \$/kg. U

   Labor cost, \$/kg. U =

$$\frac{\text{man-hours required}\cancel{\text{/eight-hour day}} \times \text{\$/man-hour}}{\text{maximum lbs. solid processed}\cancel{\text{/eight-hour day}} \times \text{(lbs. U/lb. solid or g. U/g. solid)} \times 0.45359 \text{ kg. U/lb. U}}$$

*This value is based on the stoichiometric quantity of 60% nitric acid (6.843 lbs. of nitric acid per gal.) required to dissolve one pound of alumina (Al_2O_3).

APPENDIX D

DERIVATION OF MIXING LOSS EQUATION

A parabolic equation of the form

$$Y = A + BX + CX^2 \qquad (1)$$

where Y = standard cost of uranium, \$/kg. U

X = assay, weight fraction uranium-235

A, B, and C = constants

can be fitted to uranium cost data over a limited assay range. This equation is used to derive a mixing loss equation as follows: Consider two quantities of uranium, M and N, with assays of X_1 and X_2, respectively. Then, utilizing equation (1) above, the value of the material before mixing, V_b, is

$$V_b = M\,(A + BX_1 + CX_1^{\,2}) + N\,(A + BX_2 + CX_2^{\,2}) \qquad (2)$$

The average assay after mixing is defined by the term

$$\frac{MX_1 + NX_2}{M + N}$$

This term is then substituted for X in equation (1) to obtain the value of the material after mixing, V_a, that is

$$V_a = \left[A + B\left(\frac{MX_1 + NX_2}{M + N}\right) + C\left(\frac{MX_1 + NX_2}{M + N}\right)^2\right](M + N) \qquad (3)$$

By subtracting equation (3) from equation (2), we obtain the equation for the mixing loss, dollars, which on simplification becomes

$$\text{Mixing loss, dollars} = \frac{CM}{M/N + 1}\,(X_1 - X_2)^2 \qquad (4)$$

If N approaches infinity, which is approximately the case in the feed plant, M/N approaches zero and equation (4) reduces to

$$\text{Mixing loss, dollars} = CM\,(X_1 - X_2)^2 \tag{5}$$

Thus, equation (5) determines the maximum mixing loss which would be sustained by mixing recovered oxide at one assay, say X_1, with the material in the feed plant at assay X_2.

APPENDIX E

CALCULATION OF REVISED DISCARD LIMITS WITHIN ASSAY RANGE 0.00417 TO 0.00903

Note that in table 4 there are three sets of values for solids and for solutions between the assay range 0.00417 to 0.00903. The assay in each set is applied to equation (4) in the body of this report, together with the average assay of the material processed in the feed plant, 0.0066, to obtain the maximum mixing loss in dollars per kilogram of uranium as follows:

$$L_{max} = 637{,}143\ (1)\ (0.0066 - 0.00549)^2$$
$$= \$0.79/\text{kg. U}$$

This mixing loss is subtracted from the saving of $3.76 per kilogram of uranium which is realized by processing uranium oxide through the feed plant to obtain the net saving in recovery cost per kilogram of uranium, thus

$$\text{Net saving} = \$3.76 - \$0.79 = \$2.97/\text{kg. U}$$

This net saving is subtracted from the total recovery cost corresponding to the assay of 0.00549 listed under solutions, $63.31/kg. U, to obtain the new total recovery cost, or

$$\text{New total recovery cost, \$/kg. U} = \$63.31 - \$2.97 = \$60.34/\text{kg. U}$$

The assay corresponding to this new recovery cost is found from figure 2 as 0.00540 which is the new discard limit assay corresponding to 1,000 ppm of uranium for solutions.

The above method of calculation is repeated for all the other assay values listed in table 4 within the assay range 0.00417 to 0.00903.

The new assay values so determined, together with the concentration-assay values in figures 3 and 4 which correspond to the end points of the assay range, 0.00417 and 0.00903, determine a revised discard limit curve within this assay range.

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No. 4 of 13 copies, Series A.

INTER-COMPANY CORRESPONDENCE

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UNION CARBIDE NUCLEAR COMPANY

A Division of Union Carbide and Carbon Corporation

To: Mr. E. C. Bollinger
K-1420

Plant: Oak Ridge Gaseous Diffusion

Date: February 11, 1957

Subject: Contaminated Waste Discard Criteria

KP-1150

Copies To: Mr. A. L. Allen
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The defining of discard criteria for contaminated solids and solutions is dependent upon the uranium unit recovery costs, the incremental value of the contained uranium, and the nature or characteristics of the contaminated material. Unit recovery costs include direct labor, overhead, utilities, reagents, and equipment depreciation. The incremental uranium value is based upon the determination of production costs associated with the operation of separation facilities in the gaseous diffusion plant. The nature or characteristics of the contaminated material refers principally to its chemical properties, as well as to the extent of contamination.

Approaching the waste discard problem in this manner conforms with the provisions of the Atomic Energy Commission Manual, dealing with source and special nuclear materials accountability, in which the definition is given that "strategic" value will not be considered to exceed the "economic" or dollar value. In addition to this, specific authorization has been given "to make future discards on the basis of 'marginal' cost data" (1). This means that the cost of recovering uranium from the contaminated material to hexafluoride must be compared to the economic value of this uranium. If the recovery costs exceed the uranium value, the material should be discarded; and if the uranium value exceeds the recovery costs, recovery should be effected. An evaluation of unit recovery costs was made for that equipment in service prior to the construction of building K-1420. A study of this type was again performed for the K-1420 building facilities immediately prior to the completion of construction and was based upon assumed throughputs and operating costs (2). The most recent evaluation of the current decontamination, recovery, and fluorination facilities, the results of which are contained herein, was based on operational experience (3).

Union Carbide Nuclear Company, Oak Ridge Gaseous Diffusion Plant, Operating Contractor for the U.S. Atomic Energy Commission.

UCX-163 (8-55)   This form for ~~Inter-Company Correspondence~~ only

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Classification changed to: UNCLASSIFIED
(level and category)

By authority of: CG PGD-4
(classification guide)

[illegible] 8/16/94
ADC or ADD signature (first reviewer) Date

[illegible] 9/6/94
ADD signature (final reviewer) Date

The scrap recovery capabilities and discard criteria defined in this report are based upon contaminated activated alumina as a representative solid and decontamination weak acid solution as a representative liquid. For other contaminated materials, appropriate recognition should be taken for variations in processing costs. This means that the discard data presented are to be used as absolute values only for the two materials indicated and as a guide, capable of interpretation, for other materials. In general, the data are divided into two categories. The first category is based on present throughput capacities for the K-1420 building when the effluents (condensate, waste acid, rinse water) are held to uranium contents not exceeding 10 ppm for classes A and B material, 2 ppm for class C material, and 0.5 ppm for all higher classes. It is apparent, however, that there is no justification for maintaining discard criteria for effluent flows lower than those for other materials. Therefore, a second category is included to define the economic values when the throughputs are arbitrarily assumed to be higher than the presently existing rates by a factor of 4. This increased throughput rate is not intended to have a direct application but rather is to be used as a guide in future operations.

Tables 1 and 2 show the cost of conversion from solid scrap to solution and solution to oxide, respectively, under present operating capacities. Table 3 presents the cost of conversion from solution to oxide operating at an expanded throughput. Tables 4 and 5 show conversion costs from solutions to UF_6 and solids to UF_6, respectively, on a unit basis and also present the economic recovery assays for the various initial uranium concentrations. These tables are also concerned with operations at an expanded capacity. Table 6 presents the uranium values at various assay levels with a uranium value of $17 per gram at product level and a tails assay of 0.22 being worth zero dollars. Table 7 shows the economic recovery points at various assay levels for K-1420 operations at both the present and an expanded throughput of both solids and solutions. Curves presenting this same information are also included with this report.

Additional consideration is given to the fluorination capacity and costs of the existing K-1413 operation and to the proposed high flow fluorination system in K-1420. The K-1413 system is useful at uranium-235 assays between 1 and 2%, with a cost of $7.50 per kilogram uranium. The proposed K-1420 high flow system will be capable of fluorinating oxide of unlimited assays at a cost estimated to be $7.70 per kilogram uranium. In each of these cases, a fluorine cost of $2.50 per pound was used. Changes in the economic recovery scale are shown in table 8 for both systems because of the proximity of costs. Little change is evident above 10% uranium-235 from the existing K-1420 facility on a unit cost basis. Therefore, table 8 is limited to the assay range 1 to 10%. A comparison of the economic recovery limits for the two fluorination costs above 1% assay may be determined by referring to tables 7 and 8.

J. A. Parsons

HGG:mmk

References

(1) Sapirie, S. R., letter to C. E. Center, subject "Discard of SF Material," dated September 8, 1952 (ORO-22762), Secret.

(2) Grisham, H. G., "Economic Recovery Limits for K-1420 Recovery Process," December 19, 1955 (KP-933), Secret.

(3) Center, C. E., letter to S. R. Sapirie, subject "Recovery Capabilities for Non-Irradiated Uranium," October 8, 1956 (KA-475), Secret.

TABLE 1

CONVERSION OF SOLID SCRAP TO SOLUTION

Equipment Capacity Lbs./Day	Equipment Capacity Kgs. U/Day	Grams U per Gram Solid	$/Kilogram U Unit Cost	$/Kilogram U Deprecia-tion	$/Kilogram U Total	Maximum Safe Isotopic Assay
4,800	0.03	0.000014	36,671.59	Nil	36,671.59	No limit
4,800	0.05	0.000023	22,319.29	Nil	22,319.29	No limit
4,800	0.10	0.000046	11,160.75	Nil	11,160.75	No limit
4,800	0.50	0.000230	2,231.11	Nil	2,231.11	No limit
4,800	1.00	0.000459	1,118.47	Nil	1,118.47	No limit
4,800	2.00	0.001148	447.19	Nil	447.19	80.0
4,800	5.00	0.002300	223.21	Nil	223.21	45.0
4,800	10.00	0.00459	111.85	Nil	111.85	25.0
4,800	20.00	0.00918	55.93	Nil	55.93	15.0
4,800	50.00	0.0230	22.32	Nil	22.32	8.0
4,800	100.00	0.0459	11.18	Nil	11.18	5.0
4,800	150.00	0.0688	7.47	Nil	7.47	4.0
4,800	250.00	0.1148	4.47	Nil	4.47	3.0
4,800	300.00	0.1380	3.72	Nil	3.72	2.5%

Note: Isotopic limitations for "always-safe" quantities are based on 800-pound batch sizes. At higher uranium concentrations, any isotopic assay may be dissolved by reducing the batch size below 800 pounds but the unit costs will increase proportionately. The reference solid is contaminated alumina.

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TABLE 2

CONVERSION OF SOLUTION TO OXIDE

Equipment Capacity		Ppm U in Solution	$/Kilogram U			Maximum Safe Isotopic Assay
Liters/Day	Kg. U/Day		Unit Cost	Depreciation	Total	
8,175	0.04	5	20,482.00	6,198.00	26,680.00	No limit
8,175	0.10	12	8,537.00	2,583.00	11,120.00	No limit
8,175	0.41	50	2,053.00	620.00	2,673.00	No limit
8,175	0.82	100	1,029.00	310.00	1,339.00	No limit
8,175	2.00	250	415.00	124.00	539.00	No limit
8,140	4.00	500	209.72	62.28	272.00	No limit
8,100	8.00	1,000	107.29	31.27	138.56	No limit
8,000	16.50	2,000	56.09	15.78	71.87	No limit
7,950	24.50	3,000	38.97	10.62	49.59	No limit
7,800	41.00	5,000	25.35	6.49	31.84	No limit
7,450	82.00	10,000	15.18	3.41	18.59	No limit
7,075	122.50	15,000	11.87	2.39	14.26	No limit
6,700	163.50	20,000	10.28	1.89	12.17	No limit
5,920	204.50	25,000	9.73	1.71	11.44	No limit
4,650	245.00	30,000	8.96	1.82	10.78	No limit

Note: 30,000 ppm U is optimum concentration to extraction system.

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TABLE 3

CONVERSION* OF SOLUTION TO OXIDE

Equipment Capacity		Ppm U in	Variable(1) Cost,	Constant(2) Cost,	Deprecia-tion,	$/Kg. Uranium		
Liters/Day	Kg. U/Day	Solution	$/Day	$/Day	$/Day	Unit Cost	Deprecia-tion	Total
32,702	0.065	2	251.66	771.89	253.42	15,747.00	3,899.00	19,646.00
32,702	0.098	3	251.79	771.89	253.42	10,446.00	2,586.00	13,032.00
32,702	0.164	5	252.05	771.89	253.42	6,244.00	1,545.00	7,789.00
32,699	0.327	10	252.70	771.89	253.42	3,133.00	775.00	3,908.00
32,699	0.392	12	252.95	771.89	253.42	2,614.00	646.00	3,260.00
32,687	1.635	50	257.87	771.89	253.42	630.00	155.00	785.00
32,672	3.267	100	264.51	771.89	253.42	317.23	77.57	394.80
32,630	8.157	250	283.68	771.89	253.42	129.41	31.07	160.48
32,555	16.277	500	315.45	771.89	253.42	66.80	15.57	82.37
32,407	32.407	1,000	379.04	771.89	253.42	35.51	7.82	43.33
32,116	64.231	2,000	500.79	771.89	253.42	19.81	3.95	23.76
31,820	95.461	3,000	622.76	771.89	253.42	14.61	2.65	17.26
31,234	156.169	5,000	861.11	771.89	253.42	10.46	1.62	12.08
29,769	297.690	10,000	1,427.01	771.89	253.42	7.39	0.85	8.24
28,300	424.506	15,000	1,949.17	771.89	253.42	6.41	0.60	7.01
26,832	536.637	20,000	2,427.12	771.89	253.42	5.96	0.47	6.43
25,367	634.177	25,000	2,869.49	771.89	253.42	5.74	0.40	6.14
23,898	716.955	30,000	3,261.10	771.89	253.42	5.63	0.35	5.98

*The basis for the conversion costs as shown above is an equipment capacity 4 times that which is shown in table 2. These capacities and unit costs are to be used as a guide only.

(1) These costs are for steam, HNO_3, and drying, calcining, grinding, and sampling.

(2) These costs are for direct labor, overhead, maintenance, utilities, and for Process Control Laboratory service.

TABLE 4

CONVERSION COST* - SOLUTION TO UF_6 - $/KG. U

Initial Solution, ppm	Solution to Oxide Cost	Total Cost Including Fluorination < 1%	Total Cost Including Fluorination > 1%	Economic Recovery Assays, %
2	19,646.00	19,647.00	19,673.00	-
3	13,032.00	13,033.00	13,059.00	77.80
5	7,789.00	7,790.00	7,816.00	47.20
10	3,908.00	3,909.00	3,935.00	24.15
12	3,260.00	3,261.00	3,287.00	20.35
50	785.00	786.00	812.00	5.70
100	395.00	396.00	422.00	3.30
250	160.00	161.00	187.00	1.78
500	82.00	83.00	109.00	1.24
1,000	43.00	44.00	70.00	0.742
2,000	24.00	25.00	51.00	0.58
3,000	17.26	18.66	44.09	0.52
5,000	12.08	13.48	38.91	0.468
10,000	8.24	9.64	35.07	0.424
15,000	7.01	8.41	33.84	0.405
20,000	6.43	7.83	33.26	0.397
25,000	6.14	7.54	32.97	0.392
30,000	5.98	7.38	32.81	0.389

*These costs are based on a 4 x expanded recovery capacity at K-1420.

TABLE 5

CONVERSION COST* - SOLIDS TO UF_6 - $/KG. U

Initial Solid, g. U/g.	Final Solution Concentration, ppm	Dissolving Cost	Solution to Oxide Cost	Fluorination Cost		Total Cost		Economic Recovery Assays, %
				<1%	>1%	<1%	>1%	
0.000014	2.8	36,672.00	13,032.00	1.00	27.00	49,705.00	49,731.00	-
0.000023	4.7	22,319.00	7,789.00	1.00	27.00	30,109.00	30,135.00	-
0.000046	9.4	11,161.00	3,908.00	1.00	27.00	15,070.00	15,096.00	89.00
0.000230	46.8	2,232.00	785.00	1.00	27.00	3,018.00	3,044.00	18.90
0.000459	93.4	1,118.00	395.00	1.00	27.00	1,514.00	1,530.00	9.95
0.001148	234.0	447.00	160.00	1.00	27.00	608.00	634.00	4.55
0.00230	468.0	223.00	82.00	1.00	27.00	306.00	332.00	2.75
0.00459	934.0	112.00	43.00	1.00	27.00	156.00	182.00	1.77
0.00918	1,868.0	56.00	24.00	1.00	27.00	81.00	107.00	1.24
0.0230	4,680.0	22.32	12.08	1.40	26.83	35.80	61.23	0.677
0.0459	9,340.0	11.18	8.24	1.40	26.83	20.82	46.25	0.54
0.0688	14,000.0	7.47	7.01	1.40	26.83	15.88	41.31	0.49
0.1148	23,361.0	4.47	6.14	1.40	26.83	12.01	37.44	0.45
0.1380	28,082.0	3.72	5.98	1.40	26.83	11.10	36.53	0.44

*These costs are based on a 4 x expanded recovery capacity at K-1420.

TABLE 6

RECOVER SCALE CORRECTED TO PRODUCT $17/GRAM
AND TAILS OF 0.22 = 0

Assay %	Corrected Value, $/Kg. U
0.22	0
0.26	0.547
0.30	1.984
0.50	16.78
0.7115	39.39
2.0	219.14
5.0	694.84
10.0	1,521.56
20.0	3,206.68
30.0	4,907.80
40.0	6,617.58
50.0	8,333.90
60.0	10,056.19
70.0	11,785.02
80.0	13,522.51
90.0	15,276.00
93.15	15,835.84

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TABLE 7

ECONOMIC RECOVERY POINTS

PRODUCT - $17 AND 0.22 TAILS - $0

	Solids				Solutions, Ppm U	
	Present Capacity		4 x Present Capacity			
Assay	g. U/g.	Final Sol. Conc., ppm U	g. U/g.	Final Sol. Conc., ppm U	Present Capacity	4 x Present Capacity
93.15	0.000075	15.3	0.000044	9.0	8.5	2.5
90.00	0.000077	15.7	0.0000455	9.3	8.8	2.6
80.00	0.000086	17.5	0.000051	10.4	9.8	2.9
70.00	0.000098	19.9	0.000058	11.8	11.3	3.3
60.00	0.000115	23.4	0.000068	13.8	13.2	3.9
50.00	0.000138	28.1	0.000081	16.5	15.7	4.7
45.00	0.000154	31.3	0.000091	18.5	17.6	5.2
40.00	0.000174	35.4	0.000103	21.0	19.8	5.9
35.00	0.000199	40.5	0.000118	24.0	22.7	6.8
30.00	0.000230	46.8	0.000138	28.1	26.6	8.0
25.00	0.000280	57.0	0.000168	34.2	32.5	9.7
20.00	0.000355	72.0	0.000214	43.5	41.0	12.3
15.00	0.000480	98.0	0.000292	59.0	53.0	16.7
10.00	0.000744	151.0	0.000450	92.0	87.0	26.0
8.00	0.000960	195.0	0.000580	118.0	114.0	34.0
5.00	0.001675	341.0	0.001010	206.0	200.0	59.0
3.00	0.00330	672.0	0.00210	427.0	394.0	113.0
2.00	0.00610	1,241.0	0.00374	761.0	728.0	204.0
1.02	0.0250	5,087.0	0.0155	3,154.0	3,000.0	800.0
0.99	0.0155	3,154.0	0.0078	1,587.0	1,900.0	480.0
0.90	0.0187	3,805.0	0.0103	2,096.0	2,300.0	610.0
0.80	0.0250	5,087.0	0.0140	2,849.0	3,000.0	820.0
0.7115	0.0335	6,817.0	0.0198	4,029.0	4,100.0	1,120.0
0.70	0.0350	7,122.0	0.0207	4,212.0	4,200.0	1,160.0
0.60	0.0550	11,192.0	0.0325	6,614.0	6,500.0	1,760.0
0.50	0.1250	25,437.0	0.0630	12,820.0	13,200.0	3,600.0
0.493	0.1380	28,082.0	0.0690	14,041.0	14,500.0	3,750.0
0.453	-	-	0.1070	21,774.0	30,000.0	6,000.0
0.440	-	-	0.1380	28,082.0	-	7,600.0
0.389	-	-	-	-	-	30,000.0

[redacted]

TABLE 8

ECONOMIC RECOVERY POINTS
(WITH REDUCED FLUORINATION COSTS)

Assay	Solids - g. U/g. Present Capacity	Solids - g. U/g. 4 x Present Capacity	Solutions, ppm U Present Capacity	Solutions, ppm U 4 x Present Capacity
10.00%	0.000730	0.000450	86.0	25.0
8.00	0.000950	0.000580	113.0	33.0
5.00	0.001650	0.001010	195.0	56.0
3.00	0.00312	0.00190	375.0	108.0
2.00	0.00540	0.00340	660.0	190.0
1.02	0.0190	0.0104	2050.0	600.0

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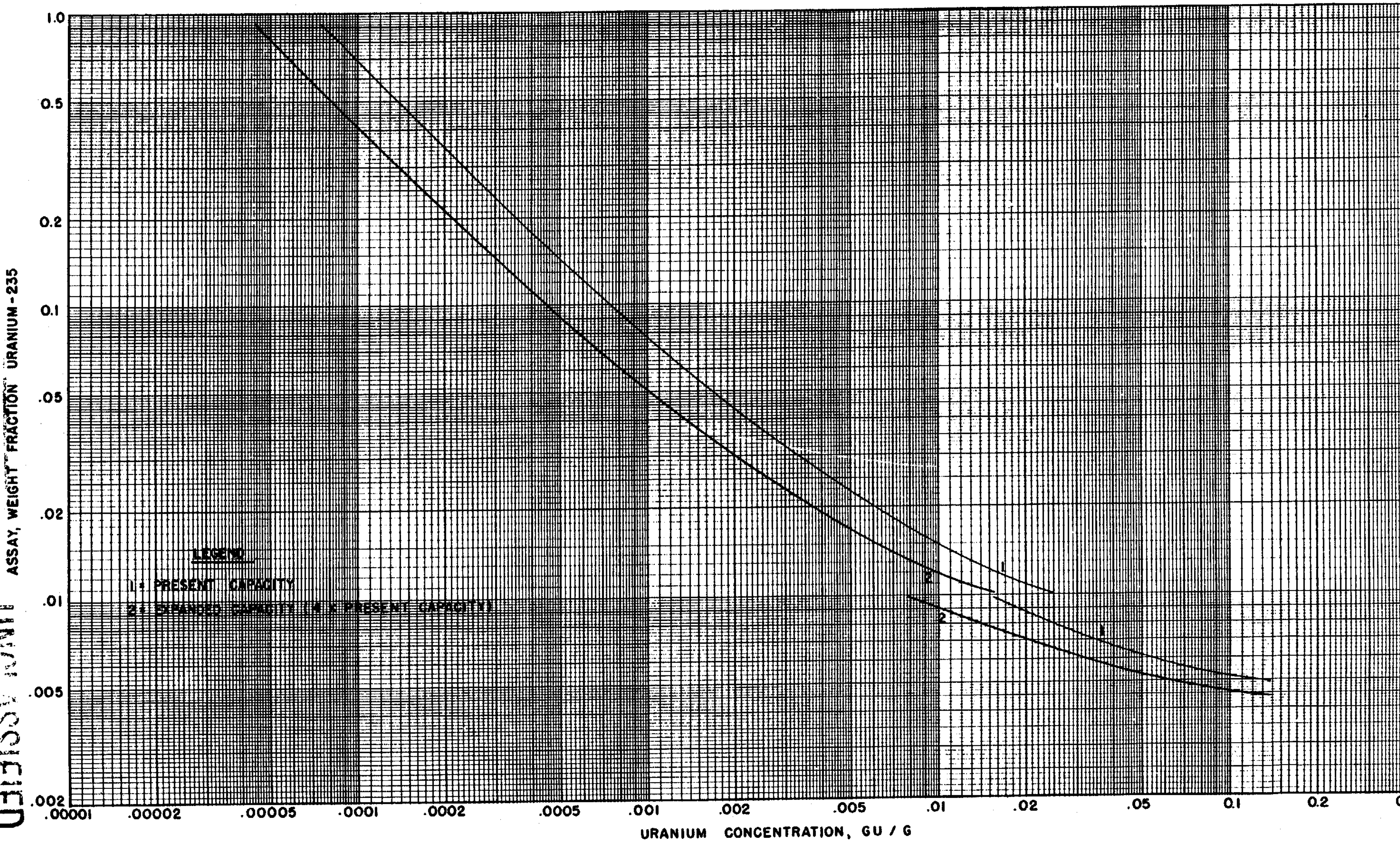

ECONOMIC URANIUM RECOVERY LIMITS - ASSAYS FOR SOLIDS

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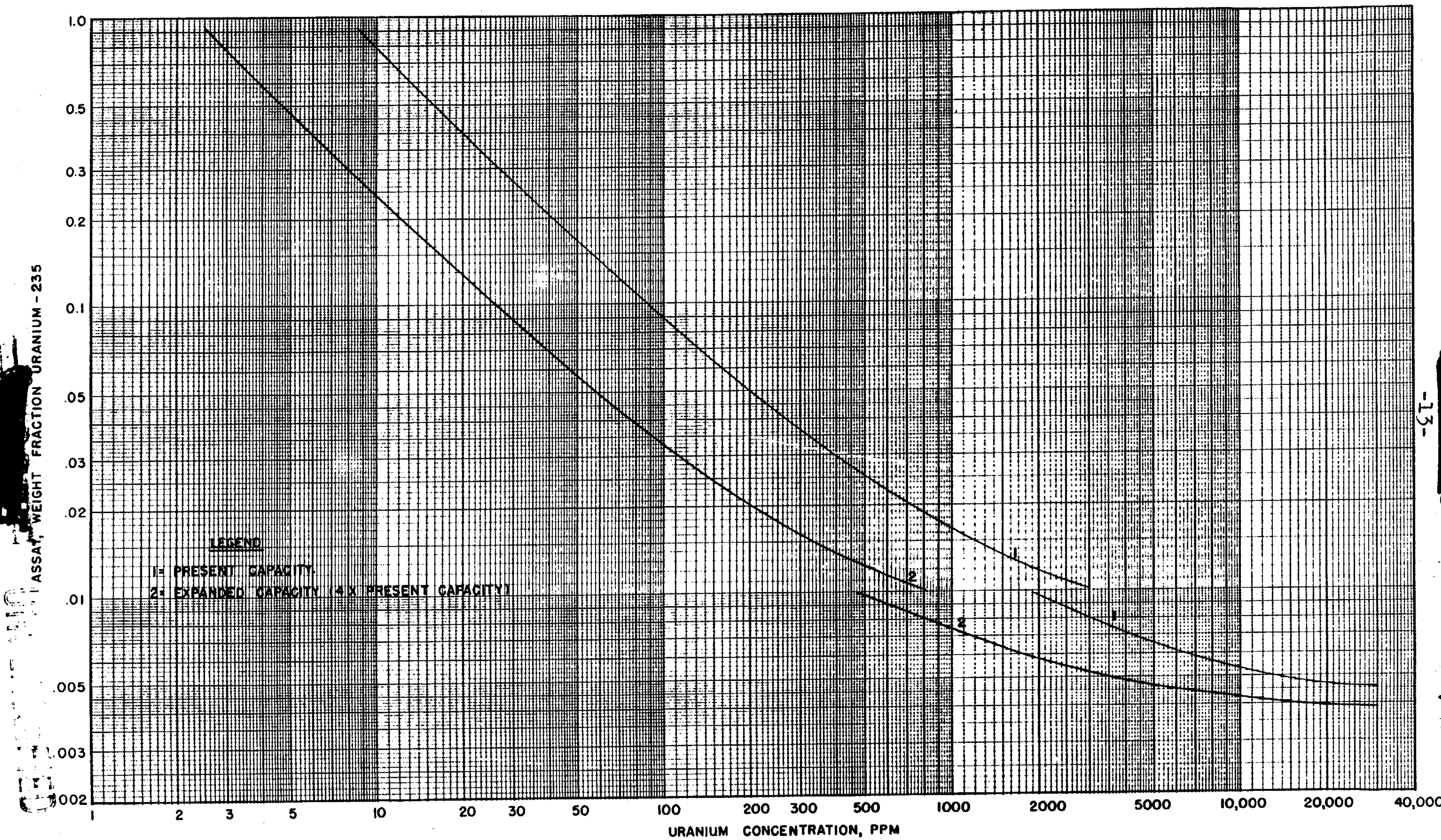

ECONOMIC URANIUM RECOVERY LIMITS- ASSAYS FOR SOLUTIONS